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Future CCS implementation in India: a systemic and long-term analysis

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Abstract

Carbon capture and storage (CCS) might be an important climate protection technology for coal-rich countries. This paper presents first results of a systemic and long-term analysis of a future CCS implementation in India. It focuses on potential storage formations in the geological subsurface and the geographic match of these sinks with CO_2 emissions of current and future large-point power plants. The analysis is framed by an overview on India's position on CCS, ongoing Indian research and development projects as well as its international activities.
The geological potential for CO_2 sequestration in India is subject to large uncertainty because, so far, only few studies estimated it in a vague manner. A first meta-analysis shows that there is a huge variation between 48 Gt and 572 Gt of CO_2. The main differences between the evaluated studies are the assumed capacities for deep saline aquifers and basalt formations. Taking the ongoing discussion and the existing uncertainties into account, the storage potential might be provided only by aquifers (in the range of 44 to 360 Gt of CO_2) and hydrocarbon fields (2 to 7 Gt of CO_2).
The amount of CO_2 emissions possibly available for sequestration is assessed by applying three substantially different long-term energy scenarios for India. These scenarios, indicating pathways between a "low carbon" and a "high carbon" development until 2050, result in cumulated CO_2 emissions between 30 and 171 Gt if all new large-scaled power plants will be based on CCS from 2020 on. Compared with the sink capacities, only the CO_2 emissions of scenario S2 (30 Gt) could theoretically be stored with high certainty. Considering the scenarios S3 and S1, their CO_2 emissions (94 Gt and 171 Gt, respectively) could only be sequestered if the aquifer capacity would prove to be usable. Geological storage sites do not appear to be located close to sources in South West, Central, North and North East India. This first rough analysis means that only those CO_2 emissions occurring in the Western parts of North and West India, the Eastern part of South India as well as the South part of East India might be suited for sequestration nearby.
A more detailed source-sink matching will follow in the next phase of the project, including results of expert meetings in India. Furthermore, this analysis will be complemented by an additional assessment from economic, ecological and resource-strategic points of view, which might further affect the potential for CCS.

Keywords: CCS; India; storage potential; energy scenario; long-term analysis

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1. Introduction

The Wuppertal Institute for Climate, Environment and Energy and the "Deutsche Gesellschaft für Technische Zusammenarbeit" (GTZ) are currently conducting a comparative international study on CCS. In a previous study on an integrated assessment of CCS in Germany Wuppertal Institute concluded that this technology is not necessarily needed in the power sector to comply with national mitigation aims [1]. Similar conclusions may well be applicable for the rest of Europe, in view of EU guidelines to expand renewable energies and increase energy efficiency. Nevertheless, globally, CCS might be an important climate protection technology: Coal-consuming countries such as China and India are increasingly moving centre stage into the debate. Although they are rapidly expanding renewable energies, this might not be enough to fulfil increasing energy demand. Thus the focus of this study is set on China, India and South Africa - three coal-rich countries and potential CCS key markets. For each of them an individual country study is being conducted, which implies a systemic perspective of CCS, considering both technical and socio-economic parameters.

Main part of the country studies is the assessment of possible CO_2 sinks, since sufficient storage space for CO_2 must be available in order to prevent the greenhouse gas from entering the atmosphere. The overall question addressed in the studies is how much CO_2 could be potentially stored in appropriate geological formations in a secure and long-term manner. The geology of potential storage formations is subject to an in-depth assessment based on a review of existing studies and relevant information and data to be gathered by local partners.

The result of the sink assessment will be a conservative storage potential which is compared with the amount of CO_2 emissions that could be captured in the long-term. For this issue an energy scenario analysis is conducted, which considers development pathways assuming different shares of fossil and renewable energies until the year 2050. Focusing on large point-sources, especially large-scaled power plants, the amount of CO_2 emissions that could be captured is quantified. The extent to which CCS could be feasible in the considered countries is finally determined by a source-sink matching and additional assessment from economic, ecological and resource-strategic issues.

This paper presents very first results of the Indian case study. The organisation of the paper is as follows: In chapter 2 an overview on India's position on CCS, ongoing research and development projects as well as the country's international activities is given. Chapter 3 discusses possible storage formations in India and analyses existing studies on the geological potential for CO_2 sequestration. In chapter 4 a long-term scenario analysis is conducted to calculate the cumulated amount of CO_2 emissions which could be separated at large power plant sources. Chapter 5 draws very first and rough conclusions resulting from the storage capacity and source analysis and gives an outlook on the next steps to be done in this analysis.

2. Status of CCS in India

The discourse on CCS in India is at a relatively early stage as the Indian government does not consider CCS as a key technology for national energy and climate policy. At the time being (summer 2010), the government prioritises modernisation and efficiency gains of India's thermal power plants towards carbon capture and storage which would significantly decrease plant efficiency. In the 2008 "National Action Plan on Climate Change" CCS is not mentioned. Instead, the Plan focuses on energy efficiency and renewable energy sources, especially solar energy. Also in 2008, the Minister of Science and Technology emphasised that technology maturity, cost reductions and clarity on all safety issues evolving around CO_2 storage would be a precondition for making CCS a technology option for India.

Despite the government's cautious position towards CCS, research and development projects on this field, both funded by the government and the industry, are ongoing. In 2007, the Department of Science and Technology (DST) established the "Indian CO_2 Sequestration Applied Research (ICOSAR) Network" in order to coordinate CCS research and development activities on CCS. Research projects are being conducted on all three major CO_2 capture pathways as shown by [2]. With regard to post-combustion capture, research on novel amine-based, multi-phased absorbents and adsorptive materials as well as processes have been initiated. These projects shall contribute to the development of cost-effective solvents, adsorbents and membrane materials. Furthermore, India seeks to investigate the opportunity of using CO_2 for farming algae. Research on high-temperature pre-combustion CO_2 capture processes has been initiated in Indian research departments. Other pre-combustion activities rather concentrate on the acceptability of high-ash coals for coal gasification processes. Indian research on IGCC technologies was kicked off in 1989 at Bahrat Heavy Electricals Ltd. (BHEL) in a pilot scale plant of 6.2 MW capacity. Coal with up to 40% ash was tested at 960°C and 1,050°C at 0.8 MPa in a fluidised bed gasifier.

On the field of oxyfuel combustion, the Centre of Excellence in Coal Research at BHEL is the leading Indian research body. As a substantial portion of Indian coal contains a high share of ash, BHEL's oxyfuel research concentrates on high-ash coal. The research centre has elaborated a roadmap for further research and development activities on oxyfuel. By the end of 2010, BHEL planned to run oxyfuel trials in a Fuel Evaluation Test Facility (FETF). In early 2011, scale up studies in a Solid Fuel Burning test Facility (SFBTF) are intended to be carried out in order to commission a 210/250 MW oxyfuel boiler in March 2013.

Different from the research and demonstration level, demonstration or large-scale projects for CO_2 capture in India melt down to a fertiliser plant where CO_2 is captured at a commercial scale for the production of urea since 1988. There are no demonstration-scale CO_2 capture tests in the power sector yet. At the fertiliser plant, CO_2 is recovered from the flue gas of the ammonia reformer unit operated by Indo Gulf Corp. since 1988. The plant is using a Fluor Econamine FGSM unit which helps to balance the NH_3/CO_2 requirements. From November to December in 2007, the plant captured 1,472 tonnes of CO_2. The following year, from October to December, 7,659 tonnes were captured [3].

With regard to CO_2 storage, there are no ongoing demonstration projects and merely a small number of planned projects. The National Geophysical Research Institute and the Pacific Northwest National Laboratory (PNNL – U.S.) are planning to demonstrate CO_2 storage in Indian basalt formations. The Oil and Natural Corp. (ONGC), India's major oil and gas supplier, is considering to use CO_2 for enhanced oil recovery (EOR) at the Ankleswar oil field (onshore).

Besides the aforementioned CCS efforts at the national level, India is involved in some international activities and networks, such as the Carbon Sequestration Leadership Forum (CSLF) or the Framework Protocol of the U.S. FutureGen initiative.

3. Potential sinks for CO_2

The geological potential for CO_2 sequestration in India is insecure because only few studies estimated it so far in a vague manner. As previously published estimates for other countries showed, the methods and selected assumptions for such analyses vary to a large degree [1]. Therefore in this study the methods and parameters applied in existing studies are systematically analysed and compared. Based on this meta-analysis it is intended to derive a cautious, conservative estimate as a lower limit which can be adjusted with future CO_2 emissions resulting from big power plant sources.

In India, potential storage sites could be located in saline aquifers, depleted oil and gas fields, unmineable coal seams and basalt formations. The *sedimentary basins* of India, where saline aquifers can be found, are at the margins of the peninsula, in the states of Rajasthan and Gujarat and with less certainty in Assam, Cachar, Tripura and Mizoram (see Fig. 1). The relevant formations are the Krishna–Godavari and Cauvery Basins, situated in South-Eastern coastal zones, and the Mumbai/Cambay/Barmer/Jaisalmer basin area in the West of India [4]. In Assam in the far-east of India, potential storage sites are in the Assam and Assam Arakan Fold Belt, connected to the rest of the country through the "chicken-neck", a 15 km narrow zone. These basins are declared to deliver "good" storage potential, if hydrocarbon fields are located there [5]. Fair storage potential can be found in Mahanadi Basin, Kutch and Bikaner Nagaur. *Coal seams* are situated especially in older Gondwana formations. Additionally, there is the enormous *Deccan basalt province* in Central-Western India.

So far, only some assessments of the storage potential, conducted more or less comprehensively, exist:

- [6] argues in his PhD thesis, finalised in 2007, that the CCS technology in India will not be restricted by geology or geography.
- [7] assume an adequate storage capacity for almost any greenhouse gas scenario (2008).
- In contrast, [8] conducted a survey with experts in 2009 and found, that there are not sufficient geological seams for storage.

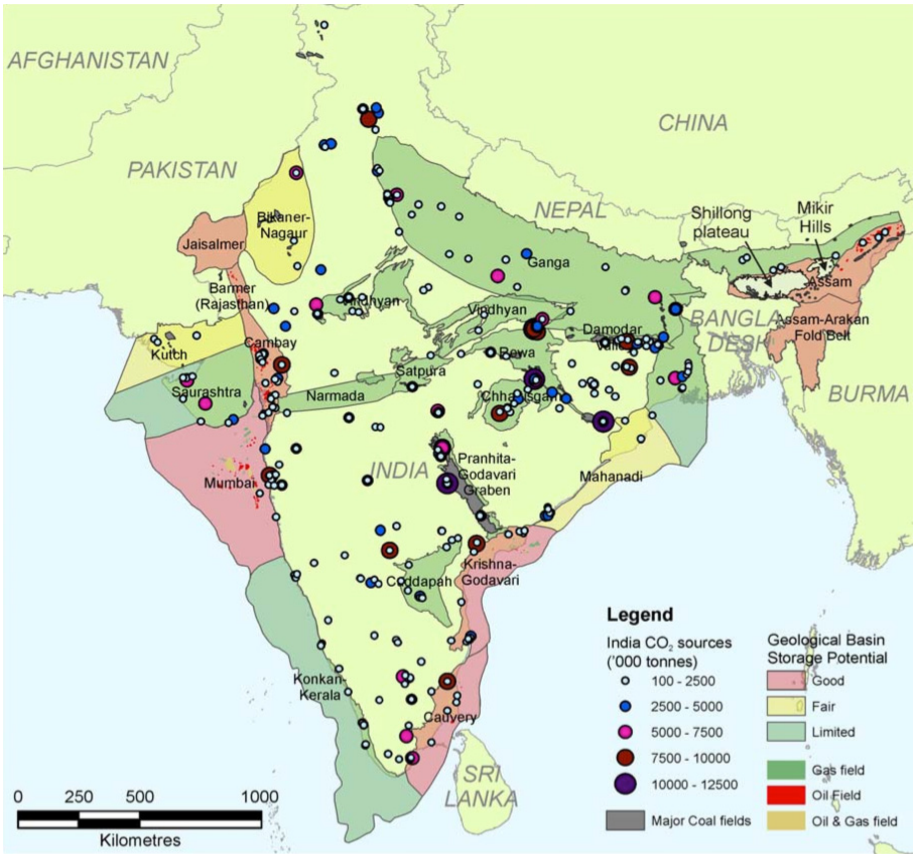

Fig. 1 Large point sources, potential storage basins and oil and gas fields of the Indian subcontinent (source [5])

- A first order global conservative estimate by [9] in 2005 delivered storage capacity in India of 105 Gt CO_2. Although no specific calculation is published, this capacity is split up in 2 Gt from depleted gas fields, 2 Gt from coal fields and 102 Gt from aquifers.
- The most comprehensive study for India published by the IEA Greenhouse Gas Programme in 2008 delivered a conservative storage potential of 68 Gt CO_2 [5]. It is summed up from the estimated limited potential of less than 5 Gt in depleted oil fields, gas fields and unmineable coal seams and 63 Gt CO_2 in saline aquifers. The general capacity calculation for saline aquifers is based on the specific storage density value of 0.2 Mt/km^2 provided by [10]. This leads to a capacity of 63.3 Gt CO_2 if the density is applied to "good" and "fair" quality reservoirs. If only "good" reservoirs are taken into account, this capacity would be reduced to 44 Gt CO_2, resulting in a total potential of 49 Gt CO_2. Additional geological information on aquifers and basalts is needed to provide a more secure and detailed estimate.
- Another specific capacity calculation for India was conducted in 2006 by [11], who estimated a total capacity of 572 Gt. This high number is based essentially on storage in deep saline aquifers (360 Gt CO_2) and in basalt formations (200 Gt CO_2). The storage capacity in oil and gas fields is calculated to 7 Gt CO_2 whereas coal seams provide additionally 5 Gt CO_2.

  Selecting the three most detailed estimates gives the overview illustrated in Tab. 1.

Tab. 1 Overview of existing storage capacity estimations for India (based on [5], [9] and [11])

<table>
<tr><td></td><td colspan="4">Author</td></tr>
<tr><td></td><td>Dooley et al. 2005 [9]</td><td>Singh et al. 2006 [11]</td><td colspan="2">Holloway et al. 2008 [5]</td></tr>
<tr><td>Oil fields</td><td>-</td><td rowspan="2">7</td><td colspan="2">1.0 – 1.1</td></tr>
<tr><td>Gas fields</td><td>2</td><td colspan="2">2.7 – 3.5</td></tr>
<tr><td>Aquifers</td><td>102</td><td>360</td><td>63.3 *</td><td>44 **</td></tr>
<tr><td>Coal seams</td><td>2</td><td>5</td><td colspan="2">0.345</td></tr>
<tr><td>Basalts[a]</td><td>-</td><td>200</td><td colspan="2">- ***</td></tr>
<tr><td>Total</td><td>105</td><td>572</td><td>68</td><td>49 ****</td></tr>
</table>

All quantities given in Gt of CO_2

* Uncertain. 63.3 Gt achieved by applying the method used for the EU to good and fair quality reservoirs (storage density = 0.2 Mt/km^2) (Wildenborg 2004, [10])

** Capacity is decreased to 44 Gt CO_2, if only good quality is requested.

*** Basalt storage is not possible nowadays because of too many uncertainties.

**** Own calculation by the authors.

[a]: including interbedded sedimentary basins → chemical trapping

The main differences between these studies are the capacities assumed for deep saline aquifers and basalt formations.

- The storage of CO_2 in *basalts* is still not substantially developed and researched, thus this possibility should be considered very cautiously.
- [5] argue that there is not yet sufficient research on Indian *saline aquifers* either. Due to the lack of information, a capacity is derived through applying the specific storage density of Europe. [5] limits the suitable aquifers to areas where hydrocarbons have been found. This limitation is not included in the estimate of [11], where a much larger area leads to a considerable higher capacity. This is a crucial difference that cannot be resolved within these first results. In the final report of this project, a deeper look at the potential storage area in aquifers will have been conducted.
- Regarding geological CO_2 storage in *deep coal seams*, depth considerations are crucial. Applying the restrictions of [5] results in a very low potential for enhanced coal bed methane recovery.

Summarising this rough discussion, the storage potential for India might be provided only by aquifers (in the range of 44 to 360 Gt of CO_2) and hydrocarbon fields (2 to 7 Gt of CO_2).

Several expert meetings will be carried out in India to complete the assessment. It is intended to get more comments on existing studies and the methodologies and parameter assumptions applied there, to be able to evaluate the capacity in basalt and aquifer formations in a more comprehensive way and to derive a conservative assessment of the total storage potential.

4. Long-term CO_2 source analysis

The amount of CO_2 emissions possibly available for storage is assessed by applying three substantially different long-term energy scenarios for India. The scenarios indicate a pathway between a "low carbon" and a "high carbon" development. For each decade until the year 2050 it is investigated which amount of coal fired power plant capacities could be installed including CCS or being retrofitted with CO_2 capture when CCS is commercially available. Based on key parameters like efficiency, penalty load, construction-time of capture facilities and capture rate, the yearly amounts of CO_2 emissions to be captured are derived. Considering the lifetime of CCS-based power plants, the total amount of CO_2 to be captured and stored can be determined. Whereas the yearly figures determine the maximum scope of the pipeline infrastructure needed for CO_2 transport, the total amount enables to determine the possible storage capacity needed per power plant, per state, per region and for India in total.

It should be mentioned, that none of the scenarios considered below include CCS so far; the second scenario excludes it explicitly. Furthermore, the Indian government does not consider CCS as a key technology as mentioned above. The aim of the scenario analysis therefore is to show how much CO_2 could be separated even in case of a "low carbon" energy economy, to compare this amount with the existing storage capacities and to conclude whether CCS would be a possible alternative to other climate protection measures.

For the scenario analysis, the following approaches were chosen. Fig. 2 shows the coal fuelled power plant capacity, resulting from the scenario assumptions.

- *Scenario S1:* World Energy Outlook 2007 Reference Scenario, published by the IEA [12]. This scenario takes into account existing international energy and environmental policies. Examples are continuing progress in electricity and gas market reforms, the liberalisation of cross border energy trade or recent policies designed to combat environmental pollution. In contrary, further policies to strongly reduce greenhouse gas emissions are not included. For this study, the Reference Scenario for India is used, which was extrapolated to 2050 by [13].
- *Scenario S2*: Energy [R]evolution scenario, published by Greenpeace and EREC in 2008 [13,14]. The target of this scenario is to reduce worldwide CO_2 emissions by 50% below 1990 level by 2050. This means that per capita emissions are reduced to less than 1.3 tonnes per year, which is necessary to prevent the rise in global average temperature from exceeding a threshold of 2°C. While the scenario is based only on proven and sustainable technologies (renewable energy sources, efficient decentralised cogeneration and energy saving technologies), both CCS power plants and nuclear power plants are excluded. For this study, the specified sustainable India energy outlook as part of the global Energy [R]evolution scenario is applied.
- *Scenario S3*: Since no further Indian CO_2 reduction scenario, which reports the installed power plant capacity per decade, could be found, the "Low Carbon Technology Roadmap" recently published by CSE (Centre for Science and Environment, New Delhi) was taken as a basis for the third scenario, a pathway between high coal scenario S1 and low coal scenario S2. Under this scenario the government is forced to undertake aggressive climate mitigation measures, supported by a strong international assistance. [15] While only 2008/09 and 2030/31 figures are given, the missing figures for 2020, 2040 and 2050 were extrapolated by the authors.

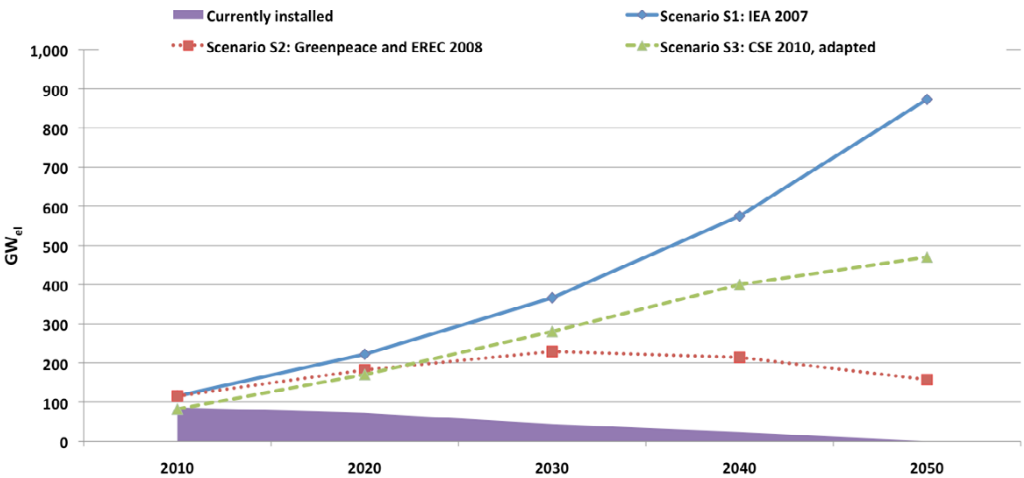

Fig. 2 Coal fuelled power plant capacity, currently installed and envisaged according to three long-term energy scenarios (own illustration)

The scenario analysis is complemented by a comprehensive analysis of power plants currently under operation and officially planned in the near future. It is based on both free and commercially available power plant databases (from CEA, CSE, IEA GHG and Platts). To determine the amount of CO_2 which could potentially be captured in the future, the following main assumptions were chosen:

- All power plants which are currently in the planning phase or which are envisaged according to the outcome of the energy scenarios could theoretically be equipped with CO_2 capture (both retrofitted and newly built ones).

- From these power plants, only large point sources (LPS) are foreseen for CCS. Since 68% of all-India cumulative emissions arise from LPS [4], 70% of the power plants are assumed to be or currently being built as large-scale plants.
- CCS will not be commercially available before 2030. From 2030 on, all large new power plants will be built as CCS-based power plants. Those ones starting operation after 2010 will be retrofitted with CCS from 2030 on.
- Power plants currently in operation will be too old for retrofitting from 2030 on.
- The Indian states are grouped to four regions, North, East, South and West, according to the official classification of the Central Electricity Authority (CEA). The power plants to be newly installed in the future are distributed in the four regions in the same relation as currently operating power plants are located.
- It is not differed between hard coal and lignite since only few lignite-fuelled power plants are assumed to be built in the future.
- All new power plants are assumed to operate on supercritical steam conditions reaching an efficiency of 40%.
- For CO_2 capture and compression an efficiency loss of 9 percentage points on average is assumed; retrofitting power plants would cost further 1.5 percentage points losses. This results in a coal penalty of 29% and 36% per kilowatthour, respectively.
- The lifetime and therefore the time for capturing CO_2 of new power plants is conservatively calculated as 40 years; in case of retrofit, the remaining lifetime (20-25 years) is used.
- The following technical parameters are set: CO_2-capture rate 90%, specific emissions of coal 331 g CO_2/kWh_{th}, full load hours per year 6,000.

The result of the scenario analysis is presented in Fig. 3. It shows that – depending on the scenarios – between 30 and 171 Gt of CO_2 could potentially be available for sequestration, if all new large power plants would be equipped with CO_2 capture from 2020 on. Considering the allocation of regions, more than one third of CO_2 emissions are produced in West India (38%) and one quarter in East India (26%), which is in accordance with the distribution of power plants (as already illustrated in Fig. 1).

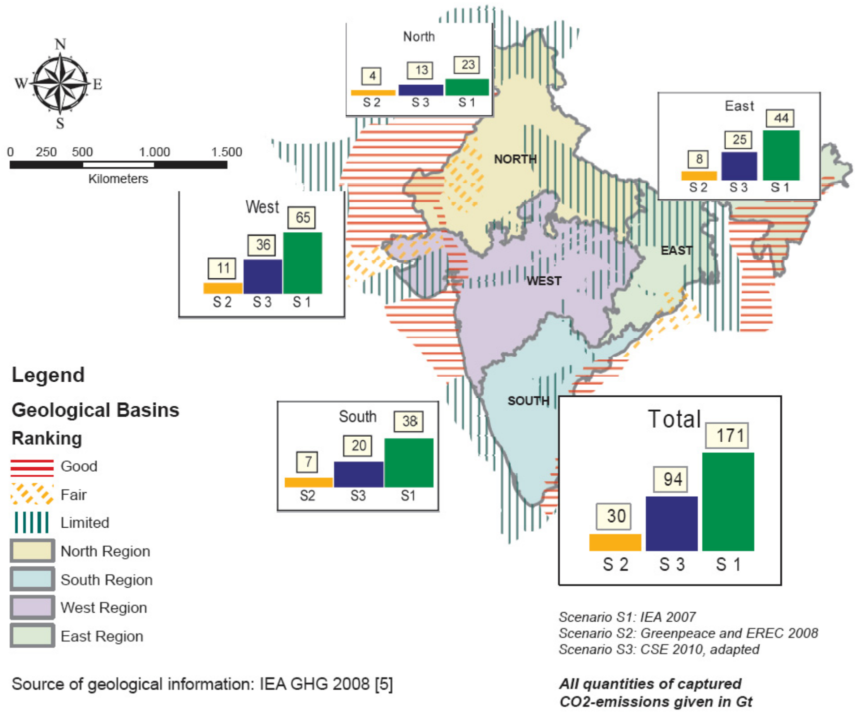

Fig. 3 Potential storage basins (taken from [5]) and captured CO_2 emissions from large-scaled CCS based power plants in India considering lifetime of 40 years as a result of three long-term energy scenarios (in Gigatonnes) (own illustration)

5. Conclusion and outlook

Taking the potential CO_2 emissions calculated in chapter 4 and the estimated sink capacities from chapter 3 into account, a qualified source-sink matching would be the next step of the analysis. However, at the current state of the project, only a preliminary conclusion can be drawn. Considering the *total* amount of CO_2 available for sequestration and comparing it with the possible storage sites, only the CO_2 emissions of scenario S2 (30 Gt) could theoretically be stored with high certainty. Considering the scenarios S3 and S1, their CO_2 emissions (94 Gt and 171 Gt, respectively) could only be sequestered if the aquifer capacity estimated by [9] and [11] turns out to be usable. So far, not included in this assessment are CO_2 emissions captured from industrial point sources which would further increase the need for additional storage capacity.

Fig. 3 also illustrates the *regional* allocation of possible sinks and emissions (shaded areas). Geological storage sites do not appear to be located close to sources in South West, Central, North and North East India [16]. Regarding the potential storage capacity in Assam, a transport of CO_2 from Indian mainland through the chicken neck can be considered as very improbable. This first rough analysis means that only those CO_2 emissions occurring in the Western parts of North and West India, the Eastern part of South India as well as the South part of East India might be suited for sequestration nearby. A more detailed source-sink matching will follow in the next phase of the project, including results of expert meetings in India. Furthermore, this analysis will be complemented by an additional assessment of economic, ecological and resource-strategic issues, which might further affect the potential for CCS.

Acknowledgments

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